

1998

APEX: A Model for Avionics Upgrade Planning and Execution

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ABSTRACT: *As our weapon systems age and fewer new systems are under development, the needs of the warfighter for more capable aircraft and systems dictate that these needs be met by modifications to the legacy aircraft the services are currently flying. For aircraft avionics, the needs for technological currency are also compounded by the mandates to operate within the safety boundaries of the National Airspace requirements. The result is a "full plate" for many weapon system managers in establishing a rational plan to acquire and install updated systems in the aircraft they are managing. The authors have defined an approach to this avionics planning process that is described as the APEX (Avionics Planning and Execution) model. The model process shows how to incorporate avionics requirements and modification planning into an effective and integrated plan that considers technical and business case issues. Concepts such as the development of an overall avionics migration strategy, the application of open systems and the use of life cycle cost in the decision process are shown to be key elements of the APEX process. Examples of the application of this planning method to execute on-going programs are provided.*

1.0 INTRODUCTION: The authors evolved the concept of APEX during a series of upgrade planning activities for Air Force legacy aircraft. The APEX embraces the systems engineering and business planning processes and is focused on structuring the information for the customer to use during the modification decision process. The need for an APEX-like process became more apparent with the requirement to install new capabilities on all aircraft operating in the National Airspace. The congressional "mandate" to install Global Positioning System capability on all aircraft by the year 2000 resulted in a number of system managers with a need to incorporate this modification into the other requirements

for their respective aircraft programs along with depot maintenance requirements. As the authors assisted several program offices and requirements study projects, it became clear that the approach to avionics upgrade planning was often piecemeal with each modification considered and funded without consideration of the relationship of a particular modification in the context of the overall aircraft capability. Additional factors such as the number of aircraft out of service and costs to "open" the aircraft for modification work were also not factored into the planning process. The end users of the aircraft were lacking an overall view of how the aircraft capability would evolve and thus uncertain of the funding implications

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D. Currently Applicable Classification Level: Unclassified

E. Distribution Statement A: Approved for Public Release

F. The foregoing information was compiled and provided by:
DTIC-OCA, Initials: VM_ **Preparation Date:** 11/20/98__

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since weapon system budgeting had been changed from the supporting commands to the using commands. The APEX then is intended to be a process model that can yield a successful modernization program that meets the user needs and applies current DoD acquisition policies. The concept provides the information for an end user approval process by incorporating cost evaluation as an independent variable and by Open Systems application to ease later upgrades and costs. APEX is an integrated approach to planning that also takes advantage of the Integrated Process Team (IPT) synergism during the development process.

2.0 BACKGROUND: The Defense Budget reductions (*Air Force Magazine*, May 1998) have resulted in few new systems under development and as a consequence have caused more modifications to legacy aircraft to extend service life and add new capabilities, both required for operations and to comply with new National Airspace rules. The budget reductions have also changed the DoD's impact on the marketplace, and together with some acquisition reform considerations, have changed the role of weapon system managers to "buyers" of systems rather than "builders" of systems. Greater use of commercially available systems, components, and parts all the way down to the computer chip level can result in avoiding non-recurring engineering (NRE) costs and permit life cycle cost savings for several reasons. Selection of system elements to integrate into a weapon system modification must carefully evaluate the expected life of the element as well as the likelihood that it will be upgraded by the manufacturer as a product in a family with later products being backward compatible with the original element. This sounds easier than it may be in actual application.

Anecdotal stories abound about families of equipment with the classic examples being the PC computer families. The components or elements on which system architectures are based vary greatly in length of service life. Figure 1 shows a recent estimate of the technological life of these various elements. Thus Open Systems application can be a challenging task in developing a systems architecture but an essential ingredient in lowering life cycle costs by permitting both competition and less complicated future upgrades. Application of the open systems concept has been, and remains, a key element of the DoD and component service initiatives under Acquisition Reform.

2.1 Acquisition Reform. In addition to the Open Systems application process being mentored by the DoD's Open Systems Joint Task Force (OS-JTF), other reforms and individual service initiatives are aimed at streamlining the weapon systems acquisition process to reflect a greater reliance on use of available commercially available products and give industry the flexibility to propose designs that integrate these products into proposed avionics modifications. While a full review of the acquisition reform initiatives is beyond the scope of this paper, the impact on the avionics upgrade of legacy systems has been significant. Many of the on-going modification programs have been influenced by the reform initiatives and have caused changes in approach such as stating requirements in terms of expected performance rather than through the application of a number of military specifications and standards in the development contract. Acquisition reform provides for only a minimum number of requirements to be specified by military specifications so that the design trade space will be broad enough for examination of a

full range of alternatives by the developing contractor.

2.2 Lightning Bolt Initiatives. As a vehicle to implement the acquisition reforms, the Air Force established the Lightning Bolt initiatives (SAF/AQ Web Pages at <http://WWW.safaq.hq.af.mil>). In addition to other initiatives, one approach is to limit the size of requests for proposal (RFP) by permitting only essential specifications and standards and in general simplifying the solicitation process. The government's goal is to move to insight into contractor's development activities rather than the traditional role of government oversight. A simplified solicitation process, requirements expressed in performance terms, and minimum "how-to" instructions could lead to the conclusion that an analysis/planning study like APEX is not required as the details sometimes worked in pre-RFP studies are now not included in RFP. In the programs where APEX-like processes were applied, the beneficial result was that the end user or customer gained a fundamental appreciation of what the modification entailed, the technical architectures that could satisfy the requirements, and importantly, the anticipated cost. The life cycle cost estimating that is a key element of APEX permits the customer to apply the Cost as An Independent Variable (CAIV) concept as part of the decision process when the program's future is being determined.

2.3 Open Systems Joint Task Force (OS-JTF). Simply stated, the concept of open systems is both a technical and a business approach that applies open (commonly available) standards principally at system interface points. This provides for understood linkages at interface points without requiring that industry open their intellectual property to competitors. With

proper system architectural structuring, later modifications or other needs to change the system can be executed with less cost and system impact. The OS-JTF was formed by DoD in November 1994 to develop the policies and processes necessary to embed the application of this concept into the acquisition of weapon systems. The Task Force has approached this challenge on a number of fronts by providing: open system definitions and policies; application guidance and evaluation; training in open systems; sponsoring pilot and demonstration programs to illustrate the concept of open systems; and capturing lessons learned from these Task Force sponsored efforts. Focusing principally on weapons systems electronics, the relationship of open systems with the other DoD system domains was also a concern of the OS-JTF as was the method to implement the policy of using an open system approach in developing the requirements, technical and systems architecture for new or updated systems and business processes. Open Systems becomes a key element in planning and executing weapon system avionics upgrade programs by permitting smaller incremental changes rather than major block upgrades or reworks of the entire aircraft or avionics system.

3.0 APEX PROCESS ELEMENTS: A cursory review of the following elements may lead the reader to conclude that APEX is merely the classic systems engineering approach to developing new or upgraded systems. While the "standard" systems engineering process is an essential ingredient, there are three unique elements of APEX. These are the development of a migration strategy for the aircraft that is time phased to the budgeting process. This shows the strategy for the system projected over the longer term, usually 10 to 15 years. A second unique element is the use of life cycle cost estimates throughout the process

to support the system engineering IPT and the customer's program decision and budgeting process. Open Systems application is the third element and the mechanism to effect the modifications and retain the ability to do later upgrades at reasonable cost. APEX can be considered to be the incorporation of new techniques for developing a technical migration strategy, performing CAIV as a recurring process throughout the pre-RFP activities and applying Open Systems. Thus in aggregate, APEX is comprised of no startling new techniques. However, the emphasis on these elements in program planning and the lessons learned from the programs that were the basis for defining the APEX, provide some meaningful insight into the application to legacy programs, and to some degree to new programs. Many of these APEX precepts came from the T-38 Avionics Upgrade Study that subsequently was approved as a formal upgrade program. This program replaces aging avionics, provides for improved reliability and maintainability, adds GPS, and will permit advanced fighter procedures to be taught in the aircraft. For the KC-135 program, some preliminary studies evolved into the development of the on-going PACER CRAG Program that is adding capability and is a first step in modernizing the aircraft cockpit. Other initial studies looked at the since cancelled Non Developmental Airlift Aircraft (NDAA) and the cockpit upgrade to the C-5 aircraft as well as several fighter aircraft studies. Some of the success of getting the T-38 and KC-135 programs through customer approval and budget request start-up can be attributed to the migration strategies that identified the viable alternatives. The life cycle cost estimates were also a key factor that let the customer determine the affordability of an upgrade program. The application of APEX is discussed in relation to the traditional steps

in a major avionics modification planning and execution process.

3.1 Requirements Analysis. The requirements analysis process may involve a formalized analysis process such as the Air Force Materiel Command Aeronautical Systems Center's Technical Planning Integrated Process Team (TPIPT) approach that involves a focal point for requirements analysis. Less formal reviews are in IPT technical interchange meetings. The user will translate the early requirements analysis into Mission Needs Statement (MNS) and later into the Operational Requirements Document (ORD). A core need to apply the APEX process is for the requirements baselining process to address all known changes, previously approved modifications, new capability or logistics performance improvements and required changes for safety and National Airspace. The requirement to add Global Positioning System (GPS) capability, for example, necessitated modification planning by each aircraft system manager. In many cases this was not a simple process because of the need to correlate this with other modifications and depot level maintenance actions. The upcoming application of Global Air Navigation and Safety and Global Air Traffic Management (GANS/GATM) to DoD aircraft may present a more complex modification planning challenge for the system managers to address. The authors expect that use of the APEX process can be a valuable contributor to the development of rational plans for individual aircraft types. Both the initial TPIPT process and many Study Managers and Development System Managers (DSM) activities that precede a formal program establishment involve the aircraft users extensively during the requirement establishment process. In the T-38 program, the users were from both the Operations and Logistics areas of the Air

Education and Training Command (AETC). Both of these areas identified requirements for the upgrade. More importantly, the users continued to be actively involved throughout the entire process of preparing the RFP and completing source selection. The users also participated in support planning and the design review process that occurs between the government and the selected contractor. The user is also key in the next step after requirements have been established: the development of a migration strategy.

3.2 Migration Strategy. Using the laundry list of requirements developed in the requirements definition outlined above, a migration strategy is next developed to describe the phases that will be developed to execute an avionics upgrade plan. A first step is prioritizing the changes to determine the business approach to upgrading the aircraft. If the requirements are extensive and it does not appear to be possible do a single modification that meets all requirements, then multiple phases should be established consistent with the DoD Planning Programming and Budgeting process and other factors such as National Airspace mandates. A top-level phase chart example is shown in Figure 2. After the determination of the number of phases, if more than one is required, the first phase should be depicted by an engineering-prepared functional flow diagram. The IPT then develops notional design alternatives for the system capabilities for that phase. This is accomplished in the form of functional flow charts developed for each of these alternatives. The T-38 study identified only a single phase for upgrade because of substantial cockpit disassembly costs and out of service times for multiple phase upgrades. Within that single upgrade phase an initial three and finally four architectural alternatives were developed for phase 1 evaluation. The KC-135 initial study

proposed three phases to complete all projected upgrades and six alternatives were developed for evaluation. Figure 3 shows the migration strategy for the KC-135 at an early stage of evaluation. This may not represent current planning for the aircraft, but served to focus the work that led to the PACER CRAG Program and illustrates the migration of the system technical architecture to show both the removed and the newly installed elements. The requirement for GANS/GATM will require further update of the migration strategy for the aircraft.

3.2.1 Single Phase Migration. A migration strategy with a single phase, while easier to define, also presents many questions that must be effectively answered to establish the formal program. Generally, smaller aircraft may best be upgraded by a single phase to avoid the high costs of cockpit and avionics bay disassembly and reassembly only to have to repeat the task three or four years later. The T-38 program completed several studies that addressed completing the upgrade in more than one phase but the labor cost, lost hardware cost for interim equipment, and user need dates all mitigated against an incremental program. These studies proved very helpful in seeking program establishment and in responding to questions during later year budget reviews.

3.2.2 Multiple Phases. The definition of multiple phases is most likely to be used for larger, older aircraft or systems that require more extensive upgrades than can be accommodated financially in a single large modification. The development of the top-level functionality to be added in each phase also serves as a catalyst to sort the requirements into rational and supportable phases. In the case of the KC-135 aircraft, the support

community and the users had been trying unsuccessfully for several years to define a modification program that would add required capability and resolve on-going support problems. These were versions of a then-called Avionics Modernization Program (AMP). Each of the AMP proposals led to the same conclusion: a single upgrade program to update the entire avionics suite was too costly. In addition, individual subsystem managers were competing to have "their" modification funded and installed without a clear perception of an overall plan for the aircraft. Recognizing that funding was a limitation to defining a successful program and that a comprehensive overall plan was needed led the Common Avionics Division of the ASC Subsystems Program office to work with the KC-135 Systems Program Office to define an initial migration strategy that incorporated multiple phases. This included a number cost studies of the alternative ways to upgrade the aircraft in the initial phase. This further helped focus the requirements and frame the architecture that eventually became the on-going PACER CRAG Program. While the GANS/GATM requirements will cause a revision to the strategy for this aircraft, as well as the rest of the DoD aircraft, the use of the migration strategy was the beneficial process that moved the avionics planning for the aircraft from the unsuccessful AMP proposals to an approved upgrade program.

3.2.3 Mapping the Strategy Selected. As shown in the KC-135 migration charts referenced above, the strategy can best be shown in top-level functional flow charts that highlight the change from the current system to the result after any particular phase is completed. The charting method shown in this description of the APEX process was prepared by Dr. Larry Brock of C. S. Draper Laboratory and

shows both the addition of new subsystems and components and the items that will be removed/modified during that phase. The functional flow charts and the top-level requirements listing by phase (Figure 2) represent the migration strategy for the aircraft and represent the proposed requirements that need to be satisfied. With this basis, the technical architectures possible for the initial phase can be defined and analyzed. Costs to lead to the start of either contract or in-house design of the actual modification can be estimated.

3.3 Architecture Alternatives. While the development of the alternatives is principally driven by the migration phase being undertaken, the out-year phases must also be considered to avoid any out-year throw-away costs for systems or components that would have a short life. Open Systems consideration is also a key consideration during this stage of defining an avionics upgrade. The benefits of applying Open System interface standards and using commercially available components from a family of products or from products with multiple sources will obviously yield outyear life cycle cost savings and permit easier follow-on modifications during later phases of upgrade. Effective alternatives are a product of extensive market research to determine the performance of available components and systems. When the technical members of the IPT are working with the engineering and marketing staffs of the manufacturers, the initial cost estimates for the expected quantity buy should also be obtained for input to the cost modeling process. The cost estimate for each alternative will be a part of the decision package presented to the IPT and customer.

3.3.1 Specific Alternatives. The market research and engineering evaluation

process will identify several viable alternatives to satisfy the functional requirements of the upgrade phase being planned. While some of the technically feasible approaches may be ruled out for various reasons, the mostly likely alternatives should be defined at the component level by preparing lists of the proposed new components. This should include actual or projected performance such as Mean Time Between Failure (MTBF) or Mean Time Between Maintenance Action (MTBMA) and expected item cost. Both the items to be removed and the items to be retained and integrated with the new components should be identified. Functional flow diagrams should be prepared for both the new and retained equipment for the IPT to fully understand the approach. These charts will also be used in the user approval process when the alternatives' performance, costs and notional schedules are presented to the support managers and users. The system level performance expressed as MTBF or MTBMA should be determined from the performance of the individual items proposed for the configuration. For the T-38 AUP three alternatives were defined initially and then a fourth emerged from the IPT evaluation process. The fourth alternative, a hybrid, was a combination of the best features of the other alternatives.

3.3.2 Information Sources.

Direct contact with manufacturers and suppliers will provide the bulk of the information needed to define and cost the alternatives. Other government and industry sources can provide valuable technical, performance and cost information. The Air Force produces and distributes an annual Avionics Planning Baseline (APB) and the Navy produces an Avionics Installation Plan (AIP). These documents describe the avionics systems on legacy aircraft as well

as provide other information organized both by aircraft and by avionics systems and components. The APB and the AIP are available to both government and industry. Cost information for components that are currently in use on other aircraft platforms can be obtained from government system managers or program offices. The alternatives can be described at the Line Replaceable Unit (LRU) or component level and provide an appropriate level of detail for cost and technical analysis.

3.4 Life Cycle Cost Estimates. Life Cycle Cost (LCC) estimates are invaluable to the user and supporter in reaching a decision about proceeding with a proposed modification. Constrained defense budgets and the changing military role from a developer of systems to a buyer of systems has established a new paradigm for the role of cost estimating. The Cost as an Independent Variable (CAIV) concept establishes cost as a control factor and encourages the appropriate trade studies during the program definition process. Early in the T-38 Avionics Upgrade study that preceded the formal program, the study manager established a criteria to present likely program costs to the user community as an element of the decision. Target costs for each avionics shipset had been informally provided and were considered as the limiting factors for a program approval. The user also had previous studies completed that estimated the costs for acquiring a new airframe rather than update the 1960s vintage T-38 aircraft. It became obvious at the outset that cost estimates would be a significant element of any decision to pursue a cockpit and associated avionics upgrade. In a similar fashion the KC-135 study that followed the T-38 effort also employed cost estimates to limit some alternatives both from an initial cost and a life cycle cost viewpoint. Thus the authors,

who were involved in both efforts, applied a CAIV-like approach before CAIV was defined as a specific formal concept. A flexible cost model can contribute to the effectiveness of the LCC estimates and provide the vehicle to quickly complete the "what-If" excursions that will occur during the review process.

3.4.1 LCC Model. The T-38 study team lead established requirements for use of a cost model that computed operations and support cost based on the predicted equipment performance of the alternatives, basing structure, program phasing, number of aircraft to be modified and the desired maintenance support concept. The Commonality Life Cycle Cost Model (COMMCOST), developed by Information Spectrum and used by both the Navy and Air Force in earlier fighter aircraft studies, was selected based on an earlier study of three different cost models. Figure 4 shows the principal features of the current COMMCOST. The cost estimates became a recurring part of the IPT process for both the T-38 study and the later KC-135 effort and the assumptions and program factors that were used in the model were collectively reviewed by the team. The cost estimates were a team product and not just an accounting "bean count". The engineers collected the costs and the expected performance for model loading during their market research effort to define the alternatives. This information was provided to the model operators, as was the user input for aircraft basing, flying hour projection, program phasing, and maintenance concept. This information permitted the model to project both the acquisition or Investment costs and the Operations and Support costs based on flying rates, MTBFs, repair costs, shipping distances and other factors consistent with the DoD's Cost Analysis Improvement Group (CAIG). For the T-38,

as a legacy aircraft, the formal program for avionics upgrade would start in the Engineering and Manufacturing Development (EMD) phase and would be essentially the integration of previously developed or commercially available components. The Research and Development costs were estimated by the engineering team using other comparable programs as an estimating reference. These costs were loaded into the model as pass-through costs. The T-38 study spanned over 18 months and considered a number of alternatives and programmatic variables while the KC-135 was a short, less detailed, two month long look at the alternatives for the first phase of an upgrade. The cost estimates were strong supporting material for the decision process and yielded several lessons learned for incorporating a CAIV process into a development program.

3.4.2 LCC Lessons Learned. The use of an IPT process that had costing inputs from several specialties and made cost an integral part of the study resulted in a sense of "ownership" of the estimates. This helped the decision review process proceed on schedule. As the analysis of alternatives proceeded, the impacts on LCC of various components was considered in relation to other configurations that provided the same functionality. By configuring the model only to compare portions of the overall system, the relative costs could be determined and used for a cost comparison rather than developing an overall LCC estimate. There are differences between a life cycle cost estimate and the PPBS ground rules for a Program Objective Memorandum (POM) input. However, These differences should be understood and the cost estimates will need to be converted into a budget request if the user decides to pursue the modification. A study team should expect a detailed and comprehensive review by the

financial staff when a program decision is made and before the program funding request is submitted in the POM. In the case of the T-38, the financial review confirmed the validity of the cost estimate and the principal activity was to convert the cost estimate to budget "rules".

3.5 Analysis of Alternatives. The analysis of alternatives represents the IPT action to review both the technical and cost features and shortcomings of the various design approaches. This process could also result in the development of additional alternatives. The integration of the proposed systems in terms of space and environmental factors are compared as are the fly-away cost and the projected operation and support cost estimates. A rating or scoring system for this process would at first appear to be of value in the comparison, but several attempts to develop such a metric were unsuccessful and the end result was a subjective review of individual factors among the alternatives.

3.5.1 Technical Analysis. In the T-38 Avionics Upgrade Study, three architectures were proposed as the most likely choices and these alternatives were then developed using the methods outlined above; market research and cost estimation. Early in the analysis of alternatives it became obvious that there was a viable fourth or hybrid alternative. The original alternatives were architectures based on MIL-SPEC equipment, commercial components or modular avionics. Each of these alternatives had some drawbacks that led to the hybrid alternative. The MIL-SPEC approach required components that were not available as military equipment. This included systems such as a Traffic Collision Avoidance System (TCAS) and others. The commercial alternative did not represent a viable alternative because some

user requirements could not be met with available commercial equipment. The Head-Up-Display systems projected to be available at the time of the study would not have the capability to be effective when used in training for future fighter pilots. The modular architecture showed many positive and desirable features but required development, and accordingly, would have increased cost and to some degree increased the risks in a formal program. During the definition of the three alternatives the "shortages" of systems were overcome by using other approaches for systems such as the HUD or TCAS, yet each alternative had some drawbacks remaining. The hybrid was a selection of the best features of the original alternatives and became part of the evaluation and cost estimating process.

3.5.2 Cost Estimate Analysis.

For each of the alternatives the production quantity cost estimates provided to the engineers by equipment suppliers during the market research were used in the cost model to calculate the investment or production costs based on an assumed number of aircraft and program phasing. The O&S cost estimate was calculated by the model based on the flying hours, basing structure, Mean Time Between Maintenance and other factors such as transportation costs for off-base component repair under a two-level maintenance. Since the proposed modification was to be basically the integration of existing capability into a legacy aircraft, the engineering cost estimates were developed from the several recent programs accomplishing comparable aircraft upgrades. Using the approach of listing the complete configuration for each alternative at the LRU level permitted the calculation of fly-away costs as well as total program cost estimates. These turned out to be important factors in the user decision process. The availability of cost estimates

based on performance, configuration and program phasing also permitted the user to request and receive the results of many "what-ifs" in the process of standing up a formal program. Later evaluation of the cost estimates confirmed the approach of getting industry quotes versus using cost models designed to estimate component costs based on weight, complexity or other technical factors. Another factor the user found beneficial in the decision process was the calculation of current support costs or baseline costs for the unmodified aircraft using the same cost factors as was used in the alternatives costing. The cost estimates were clearly an independent variable in reaching a program decision. Comparisons showed that electing to not pursue the program would result in approximately the same life cycle costs over 20 plus years but would not gain the ability to teach advanced training tasks and stop the declining avionics reliability. See Figure 5. The authors presented this chart to the using command's project managers and this became a factor in presenting the concept to senior management for program approval. The issue of requiring a large up-front expenditure to gain the overall life cycle advantage was a key consideration, but the declining performance and usability of the aircraft as a pilot training platform was a deciding factor. The cost estimates confirmed that the upgrade was an affordable program.

3.6 Program Approval. The results of the analysis of alternatives provide the vital data for the approval of an avionics upgrade program. A major pacing item that served to move for an early decision on the T-38 program was the requirement to have Global Positioning System (GPS) installed on the aircraft by the year 2000. The method to add this capability and the decision to integrate the GPS into the

navigation solution display for the pilots resulted in several additional small studies to look at options for adding GPS first or including this as part of the upgrade program for the entire avionics suite. All DoD aircraft basically faced this timing dilemma in adding this capability. While this was a difficult process for several programs, the T-38 avionics upgrade study provided the technical and cost impact information to develop a rational and defensible plan for the aircraft. Programs that did not have a migration strategy for the aircraft being managed were in the position of resolving production conflicts with individual modifications and maintenance requirements. The authors are convinced that changes to National Airspace requirements will pace aircraft avionics changes and will occur again in the next several years as the GANS/GATM modifications and timing are solidified. Program approvals will likely be an iterative process, but demonstration that market research has yielded viable alternatives and that adequate cost estimates have been done with the involvement of the user community present a strong argument for the modification program. Both the supporting commands and the using commands will have a role in the approval process. This will usually require strategic and tactical program roundtables and the "conversion" of the cost estimate into a budget request by factoring in lead times and any changes from the financial management review of the estimate. Program approval should also fully consider the future expandability and flexibility that can be attained in an upgraded system. As a buyer of systems, the Open Systems approach advocated by DoD through the OS-JTF will provide outyear expandability and flexibility, avoid obsolescence and provide life cycle cost savings. Pilot and demonstration programs that the OSJTF has helped sponsor with the

services and industry have shown the potential of using commercially available components and software in our military systems. Open Systems have become a favorite word choice in many requirements documents, but unless fully considered during the decision process will not provide the ability to attain the outyear benefits of the use of open, commercial systems.

3.7 Solicitations for Avionics Upgrades. For post-production legacy aircraft, many avionics upgrades will be of the scope that requires a competitive solicitation and source selection process. Acquisition reform has changed the way requirements are stated in the Requests for Proposal (RFP). The old way of specifying requirements was to list numerous military specifications and standards to be used in the design process. Now the approach is to state the required performance for the system being acquired using very few specifications, or at best, using industry recognized open standards. Reviews of government requirements documents will likely show a requirement for Open Systems and the industry response to RFPs will propose that the design that will be provided will be based on Open Systems application concepts. The full incorporation of the Open Systems process requires greater emphasis on evaluating how the proposed design provides for expandability, flexibility, and affordability. The RFP should clearly indicate an intent to use these factors as major elements of the source selection process.

3.8 Source Selection. During the source selection process, the proposals should be carefully evaluated based on the degree of openness provided by the design. Open Systems designs could initially cost more but provide the framework for later modifications or upgrades. However, a clear

ability to minimize later hardware or software costs can be the basis for a best value source selection that recognizes the innovation of a life cycle approach rather than one-time cost as the criteria.

3.9 Upgrade Program Execution. As an avionics upgrade program moves to the design stage, the openness of the design and the performance of the support factors such as MTBF or MTBMA should remain up-front considerations in approving the various design review levels that have been established for the program. With the acquisition reform goal to change government oversight to government insight this may represent a paradigm shift for the industry/government teams in the execution of a large avionics upgrade program.

4.0 APEX OPERATING PRINCIPLES. The APEX approach can be accommodated best by the use of the operating principles that the authors have observed during a number of avionics planning efforts. These are, in effect, the lessons learned in how to apply the concept to better develop and manage the avionics capability and currency for an aircraft type.

4.1 Use an Integrated Product Team Approach. Both government and industry are quick to indicate that an IPT approach is being used, but to make the process more than a series of meetings requires an open forum where viewpoints and approaches cut traditional functional boundaries and become task oriented. For upgrades that occur during a production run, this may represent the on-going discussions between the prime contractor and the government program office. For legacy programs that are out of production, the effort will be mainly a government process with industry interaction through the market research process and through pre-solicitation industry

days and other forums. For both the T-38 and KC-135 studies, the definition of alternatives, collection of performance and cost data, and the preparation of decision information was undertaken by a team that generally ignored the traditional functional boundaries. The collection of the quantity cost estimates by the study engineers to insure that costs of a proposed unit are consistent with required LRU performance is an example of a task orientation rather than the traditional functional approach.

4.1.1 IPT Operation. Early in the definition and development of the architectures that will be evaluated as alternatives, the tendency of the IPT can become a process of trying to "design around a conference table". The IPT should appropriately assign tasks for presentation to the group and hold frequent meetings to check results and progress.

4.1.2 User Involvement. The direct and continuous involvement of the aircraft users and supporters in the IPT is necessary to retain a constant focus on the requirements the upgrade is working to provide. In the T-38 study, both the operational users and the logistics supporters were involved from the start of the IPT, as the upgrade is to provide improvements in both areas.

4.2 Migration Strategy is Key. The migration strategy provides a method to set the overall framework for incorporating ongoing modifications, National Airspace requirements, and new operational and supportability requirements into a cohesive and executable program. The migration strategy integrates the known requirements, facilitates the definition of upgrade phases, and permits consideration of open system approaches and affordable upgrade programs consistent with available user

funding. A migration strategy is useful in getting user buy-in for the upgrade approach before the full study resources are applied to alternative definitions and cost estimations. New alternatives for possible architecture alternatives can and most likely will occur, but the migration strategy works from a usually consistent set of user requirements. This requirement set can also benefit the user's formal requirements process through the Mission Needs Statement (MNS) or Operational Requirements Document (ORD). The migration strategy should be based on an executable notional schedule which will also serve as the program shell for the cost estimate process. Several past efforts to develop avionics roadmaps have been attempted but these became listings of individual modifications, usually at the LRU level. These roadmaps did not integrate the requirements into a strategy that considered all requirements and generally were designed to show modification funding status and not to serve as a tool to plan the future of the avionics system for the respective aircraft.

4.3 Cost as An Independent Variable. The use of cost estimates for the evaluation of alternatives permits to users to select the desired alternative and address the affordability of both the strategy and the upgrade phase being considered. The cost estimates developed for the T-38 were fairly detailed and showed the impact on life cycle costs as well as the near-term costs for the first phase of the strategy. This cost information served to provide a source of information to answer many questions during the formal decision process and became the basis of the program budget. During a timeframe where budgets were tightening, the ability of the program to proceed from study to a new start avionics upgrade program is attributable, at least in part, to the cost information available to the

program managers. Use of a flexible cost model, such as COMMCOST, that can be structured to closely match the proposed program and run excursions and sensitivities is a major help in the approval process and the program stand-up. The cost estimation process can also provide unexpected benefits in an APEX process. In one program, the support agency was developing a modification to replace a particular avionics component. Model runs showed that the modification would actually degrade LCC, as the component proposed to be replaced was not the factor in the performance degradation. Associated components were the problem driving the costs and this was demonstrated to program management. The result was the deletion of the modification in favor of a different solution embedded in a phase of a migration strategy.

4.4 Open Systems and Migration Strategy. While an aircraft avionics migration strategy could be based on products with closed, propriety interface standards products, this does not permit later modifications at least cost nor take advantage of the commercial upgrade of families of equipment. The addition of a new avionics component through a modification only to have that component removed for scrap a few years later because of a system interface requirement can be avoided by keeping an Open Systems approach throughout the planning process. As discussed above, Open Systems concepts and approaches should be clearly stated and evaluated during the solicitation and source selection. Open Systems are also a factor that should be considered during the market research conducted to define alternatives. Selection of technologies that are predicted to become obsolete or do not have an open interface defined can result in the throw away costs when new capability is added

later. The degree of openness of a proposed system is difficult to measure and not all architectures can be fully open. The goal is not Open Systems as an end unto itself but the ability to affordably upgrade and sustain fielded systems. Open Systems application guidance is currently being emphasized by in-work changes to the Joint Aeronautical Commanders Group's (JACG) Performance Based Business Environment (PBBE).

5.0 APEX PROGRAMS. Since the APEX process as defined in this paper has evolved over a six year time period while working the referenced programs and other similar avionics studies, no single upgrade program has applied all of the APEX principles. Notably, the T-38 Avionics Upgrade Study that transitioned into the T-38 Avionics Upgrade Program (AUP) is now approaching first flight. The T-38 study provided a large measure of the insights from which the APEX was defined. The KC-135 avionics study was an abbreviated study, but provided an opportunity to understand the ramifications of an upgrade that would require multiple phases to accomplish. The authors are currently working with avionics modernization for an aircraft still in production for which managers are coming to grips with the retrofit needs and the pending GATM requirements. We suspect that the APEX will further evolve during this effort. The authors do not claim that APEX represents all new concepts. However, it is an approach to avionics planning and execution that emphasizes use of a migration strategy, life cycle CAIV cost estimation and the application of Open Systems concepts.

6.0 ACQUISITION REFORM. The ongoing acquisition reform process could be viewed as presenting a paradox with a proposition that advocates detailed analysis of the architectural alternatives, cost analysis

and Opens Systems concepts. If the government will only specify performance requirements and industry will propose the design solution then what is the purpose of the up-front and rather detailed study? The authors do not share this view. While there is a level of frustration in stepping through the design process a second time, the market research sets the framework for understanding the range of possible solutions. The cost estimates were invaluable in the program approval and in the establishment of a budget for the program standup. The Open Systems approach can provide the "building codes" that let us upgrade avionics rationally, affordably and within the timeframes of warfighter needs. While acquisition reform has changed many paradigms and concepts, APEX does not appear to be at odds with this new way of doing business.

7.0 SUMMARY. The planning and execution of avionics upgrades for legacy aircraft can be a challenging process for system and program managers as they work to incorporate warfighter needs into the aircraft systems in a timely and affordable manner. Over the past six years the authors have been involved in a number of avionics planning and execution programs and have defined the APEX model process from that experience. The APEX suggests that an overall migration strategy for the avionics upgrades, greater use of Life Cycle Cost estimation and the application of Open Systems concepts are the three principal legs of the process. The authors are more than willing to discuss the APEX process and share their enthusiasm for improving the avionics planning process, a core ingredient in mission execution.